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# DEVELOPMENT AND EVALUATION OF AN L-BAND RECEIVER PRE-AMPLIFIER AND A TRANSMITTER POWER AMPLIFIER

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DEVELOPMENT AND EVALUATION OF AN L-BAND RECEIVER PRE-AMPLIFIER AND A TRANSMITTER POWER AMPLIFIER


## SUMMARY

This report describes the development and evaluation of (1) a low-noise rf amplifier designed for use as a pre-amplifier for the receivers of standard CAA, Type DTB, DME transponders, and (2) a high-powered crystal-controlled pulse transmitter employing a klystron as an output power amplifier. Use of the latter is not restricted to DME transponder applications; however, in combination with the pre-amplifier it permits the assembly of a DME transponder providing a maximum range capability approximately double that of a standard DME transponder. In the course of evaluation of the high-powered, high-sensitivity system, it became evident that the sensitivity and power output of standard transponders is adequate to meet most present-day operational needs and it is recommended that implementation of the improved system be limited to special applications.


## INTRODUCTION

It is difficult to predict with accuracy the reliable range capability of UHF communications equipment. This is particularly true when either the sending or receiving station is mobile as is the case in the DME system.

Given a fixed set of system characteristics including antenna gains, power outputs, frequencies and minimum detectable signal levels, one may arrive at a theoretical maximum useful range, usually referred to as the free-space range of the system under investigation. See Appendix I. Major deviations from a range capability computed in this manner occur in practice due primarily to the following variables:

1. Variations in effective antenna gains with distance, elevation, and aircraft attitude.

2. Instability of equipment characteristics; primarily frequency, power output, and receiver sensitivity.

3. Atmospheric conditions.

4. Terrain features between the transmitting and receiving points.

Operational experience with DME systems during the past seven years has shown that reliable solid coverage to radio line-of-sight is not always achievable due to one or more of the above variables.

Recent rf amplifier tube developments, completed subsequent to the time when the design of the present DME system was finalized,[1] showed promise of increasing both the power output and the receiver sensitivity of DME transponders appreciably. One of these tubes, identified as SAL-39, a klystron developed by the Sperry Gyroscope Company, proved suitable as an rf power amplifier capable of peak pulse power outputs of the order of 20 kw at DME duty cycles, compared to 6 - 8 kw output for standard transponders at a maximum duty cycle of approximately one per cent.

Recognizing the potential value of such a tube, the Air Navigation Development Board in 1949 awarded a contract through Evans Signal Laboratories for the development of high-powered crystal-controlled transmitter capable of operating anywhere in the frequency range of 960 - 1215 Mc. By specifying operation throughout this band, (allocated for use by all common system navigation aids[2]) rather than restricting its use to DME which occupies the 960 - 990 Mc and 1185 - 1215 Mc portions of the reserved band only, the transmitter has far wider application potential. This unit is referred to hereafter as the MOPAT (master oscillator power amplifier transmitter).

The other tube development which played a significant part in the program described in this report is the low-noise Western Electric WE-416A rf amplifier tube. This tube was employed in a specially-designed cavity suitable for installation in a standard DME transponder preceding the existing crystal mixer. In this case the tuning range design was limited to the interrogation frequencies 960 to 990 Mc portion of the DME band. This development was also sponsored by ANDB and carried on by the CAA Technical Development and Evaluation Center.

## THE RF AMPLIFIER

Hazeltine Electronics Corporation was awarded the contract for development of the radio frequency amplifier. Preliminary studies conducted by the contractor plus the fact that the only other tubes promising equivalent performance were still in development stages, led to the selection of the Western Electric 416-A tube for the amplifier, based on a relatively simple cavity design. The 416-A tube is a parallel plane microwave triode.

[1] R. C. Borden, C. C. Trout, E. C. Williams, "UHF Distance Measuring Equipment for Air Navigation," CAA TD Report No. 114, June 1950.

[2] RTCA Paper 27-48/DO-12, 1948. Report of Special Committee 31.

In the final design of the amplifier and associated cavity, input coupling was accomplished through a Type BNC jack which is connected to a post located inside a 1-1/2 x 3/4-inch waveguide mounted on the side of the cathode cavity. This post is coupled to a second post tuned to match the 52-ohm preselector output impedance to the cathode cavity input impedance. The plate cavity is tuned by a dielectric slug injected into the side of the cavity. The completed rf amplifier is shown in Fig. 1. A disassembled view is shown in Fig. 2, while Fig. 3 depicts the amplifier installed in a DTB transponder. Figure 4 is the schematic diagram. One of the specification requirements dictated that the mechanical and electrical design of the amplifier be such that installation can be readily accomplished in the field by maintenance technicians. This requirement was met and the entire installation can be accomplished in less than one hour.

All power required for operating the rf amplifier was obtained from power supplies already contained in the DTB transponder. A control chassis is included as a part of the amplifier installation. This chassis contains the necessary fusing and a meter jack for monitoring the cathode current. A monitoring meter, also a part of the transponder, is used for this purpose.

Following initial tests at the manufacturer's plant to determine that the specification requirements had been met, the rf amplifier was delivered to the Technical Development and Evaluation Center for tests in an operating DTB transponder and for operational evaluation.

Tests conducted at TDEC revealed an average improvement in overall sensitivity of the DTB receiver of from 3 to 6 db depending upon the initial sensitivity of the receiver prior to addition of the rf amplifier. The receiver sensitivity specification for the DTB transponder specifies a 50 per cent triggering level of 118 dbw; however, in actual operation most units are providing 120 to 121 dbw. When the original sensitivity is no better than 118 dbw, the addition of the pre-amplifier usually results in an increase of up to 6 db. If the original sensitivity is above 120 dbw, correspondingly less increase in sensitivity is obtained.

A life test was conducted on the rf preamplifier so that data could be obtained relative to gain, stability, and tube life. In order to leave the DTB equipment free for other tests, the rf preamplifier was removed from the transponder and installed in a bench setup to simulate actual operating conditions. See Fig. 5.

The bench setup to test the preamplifier consisted of the following equipment:

1. Two Aircraft Radio Corporation VHF signal generators, Model H-12; one used for the local oscillator, and the other providing an rf input pulsed at 4000 pps.

2. A 30 Mc if amplifier and detector with a bandpass of 6 Mc.

3. A generator that developed an accurate 30 Mc pulse so that the gain of the if amplifier could be adjusted if needed when measurements of the rf amplifier gains were made.

4. A Tektronix 512 oscilloscope to measure the amplitude of the detected signal.

5. A wavemeter to detect any drift of frequency in the ARC generators.

6. Regulated power supplies for all B+ and bias voltages.

7. Fan assembly for cooling the cavity of the preamplifier.

Readings were periodically taken of plate current of the rf amplifier and of the rf input level necessary to maintain a fixed amplitude of detected pulse.

The plate current of the rf amplifier began to increase somewhat after 900 hours, from 24 ma. to 24.5 ma. at 954 hours; from 24.5 to 25 ma. at 1099 hours, and from 25 to 25.5 ma. at 1589 hours. The test was conducted continuously for 1665 hours. The record of the rf input necessary to maintain a fixed detected amplitude, at approximately 2:1 signal to noise, showed no greater change of input than 1/2 db during this time, the limit to which measurements could be made. The tube had not failed at the conclusion of the test.

Flight tests of the ground receiver, other than those conducted during the B-36 flight described later, were confined to determining the relative strength of the DME interrogation and reply paths. With the airborne equipment employed in these tests, it has been observed almost invariably in the past that the interrogation path failed prior to the reply path. When using a standard DME transmitter on the ground, but with the rf amplifier installed ahead of the standard receiver, the converse was invariably true. An examination of the interrogators in use and the ground station equipment revealed the above finding to be contrary to theory; however, earlier systems employed relatively poor control of interrogator output frequency and it is probable that a 2 to 3 db degradation in the effective strength of the interrogation path resulted thereby.

## THE MOPAT

The development of the MOPAT was conducted under the supervision of the Evans Signal Laboratories by Westinghouse Electric Corporation.[3] The Technical Development and Evaluation Center did not become active in the project until the equipment had been accepted by the United States Army and shipped to the Center for evaluation.

The MOPAT consists of a complete crystal-controlled transmitter, modulator, and associated power supplies which can be operated in conjunction with any DME ground station. The unit requires only that trigger pulses of the proper timing and spacing be fed to it from the associated DME transponder. This arrangement allows the MOPAT transmitter to operate independently of the ground station transmitter and simultaneously with it, on the same frequency, and in reply to the same interrogation.

Preliminary steps in the evaluation consisted of determining that the MOPAT met the engineering requirements of the specification. Of major interest were power output measurements at various duty cycles. It was found that the MOPAT delivered a minimum peak power output of 20 kw up to a duty cycle of one per cent. Output power was reduced when operating at higher duty cycles in order to maintain an equivalent average power.

The original installation of the MOPAT at Indianapolis was made in the same building in which a standard DTB DME transponder was installed. A separate antenna was used for the MOPAT at the same height (35 feet), but removed from the DTB antenna by approximately 60 feet. The two antennas were electrically and mechanically identical. A view of the MOPAT and the DTB transponder installed is shown in Figs. 6 and 7, respectively. No major problems were encountered in the MOPAT installation except that it was necessary to install a ventilating duct with fan attached to the top of the MOPAT cabinet. This was done primarily for the comfort of project personnel rather than of fear that ambient temperatures might be detrimental to proper operation of the unit. The MOPAT was later installed at a different site, without benefit of a ventilating fan, where it operated satisfactorily during life tests.

## MOPAT FLIGHT TESTS

Following engineering tests, flight tests were conducted on the MOPAT to determine the increase in coverage over a standard DTB transponder. As a convenience to flight engineering personnel in

[3] Westinghouse Electric Corporation, Report TT-48991C-21, March 1953.

establishing the relative signal amplitudes, both the MOPAT and DTB equipments were tuned to the same transmitting frequency; namely, 1188.5 Mc. All interrogations were received by the DTB receiver prior to installation of the rf amplifier. After decoding, the video signal was permitted to follow its normal path and trigger the DTB transmitter; but it was also diverted and delayed approximately 100 microseconds and used to trigger a double-pulse generator which in turn triggered the MOPAT. A block diagram of this arrangement is shown in Fig. 8.

With this arrangement, the output of the interrogator receiver when viewed on a synchroscope appeared as in Fig. 9, in which both reply pairs may be seen. In the course of observation, it was noted that although the MOPAT reply was generally stronger, as expected, in some cases the DTB reply was stronger, due to the fact that the two transmitters were using separate antennas.

In order to determine quantitatively that a net gain was being realized from the higher powered MOPAT transmitter, a number of field strength patterns were obtained for the MOPAT and DTB transponders. A typical polar pattern is shown in Fig. 10. At this time the DTB was operating at a relative power ratio of only 3 db below the MOPAT. Field intensity is expressed in decibels above minimum tracking level for the interrogator.

Due to the line-of-sight limitation imposed by the altitude ceiling of the DC-3 aircraft, it was not possible to determine operationally the maximum range obtainable with either the MOPAT or DTB. In most cases observation of the interrogator receiver output revealed saturated reply signals at the time of approach to the radio horizon, followed by rapid reduction in field strength to the threshold level within a distance of 5 to 8 miles. In general, the added power of the MOPAT under this condition, did not provide more than an additional 2 or 3 miles distance at the radio horizon. This is in accordance with previous experience with similar systems.

## MOPAT LIFE TESTS

To obtain information relative to the maintenance requirements of the MOPAT it was decided, after operational tests had been concluded, to let the equipment operate continuously, triggered by an external generator at a high duty cycle. This test lasted a total of 1575 hours. Maintenance was required four times during this period. The longest interval of maintenance-free operation was 695 hours.

A Berkeley Model 9035 double-pulse generator was used to provide a trigger for the first 324 hours of the test. The pulse spacing was 14 microseconds at a prf of 2600, the maximum obtainable from the generator. This resulted in a duty cycle of 0.65 per cent. The trigger for the final 1251 hours of the test was provided by a Hewlett-Packard Model 212A pulse generator running at a pulse rate of 4040 pps, thus driving the transmitter at approximately one per cent duty cycle. Readings of all meters were recorded periodically. A Berkeley Model 554M pulse counter was used to adjust the pulse rate. A Polarad Model ASA spectrum analyzer was used to monitor output pulse shapes.

The first failure occurred at 144 hours. The transmitter lockout sequence had occurred and the first tripler grid current was negative. This tube, a 4X150A, is used to deliver about 60 watts peak at 328 to 405 Mc. in the MOPAT multiplier chain. It was replaced after a total life of 568 hours, and upon application of the 300 - 1700 volts dc plate voltage, the first tripler grid current read correctly positive. When the high voltage was applied, the transmitter again went through the lockout sequence and no output was obtained. This was caused by a high voltage arc-over to ground. The arc-over had occurred on the line to the modulator plates at a plastic feed-through bushing in the modulator chassis. A break in the insulation of this line was repaired with Scotch No. 33 electrical tape. The MOPAT was then restored to operation.

After 16 additional hours of operation, arc-over of the high voltage on the same cable to the modulators occurred again. The arc-over occurred at a different point from the previous failure. The entire high voltage cable and plastic feed-through bushing were then replaced. The modulator was cleaned of dust, the front panel was replaced, and the MOPAT was placed back into operation. The repeated arcing-over was probably due, in part, to dust that had collected in the modulator portion of the chassis. Improper operation of the ventilating system without the front panel that covers the rf alignment adjustments accounted for the collection of dust.

At 328 hours of this test (total life of 752 hours) a 2E26 tube failed and was replaced. This tube is used as a doubler in the multiplier circuits. After running continuously for 548 additional hours, the MOPAT was shut down to replace a modulator tube, Type 4X1000, which had dropped below the specified current tolerances. The total life of this tube was 1303 hours. The other modulator tube dropped below the specified current tolerance after 695 additional hours of continuous operation. The total life on this tube was 2000 hours. The life test was terminated after a total of 1575 hours.

It is concluded from this test that the MOPAT design is adequate to provide ultimately an equipment capable of unattended operation on a continuous duty basis provided that dual installations, automatic transfer, and suitable maintenance equipment are added.

## B-36 FLIGHT TEST

Although statistical analysis of the DME system indicated that range of 300 miles could be obtained, assuming that line-of-sight prevailed (see Appendix I), it was desired to demonstrate distance measurement to this range. Through the Air Navigation Development Board, arrangements were made with the USAF Strategic Air Command to install several interrogators in a B-36 aircraft and to conduct a special flight test using the high-power MOPAT, high-sensitivity rf amplifier, TDEC station. Computations indicated that an altitude of 45,000 feet would be required in order to maintain line-of-sight at 300 miles.

The aircraft installation was made in a B-36 aircraft at Ellsworth Air Force Base, Rapid City, South Dakota. The DME interrogators employed could be mounted conveniently in existing shock mounts which made the installation relatively simple. Both 400 cps, 115v ac, and 28v dc were available in the B-36.

Previously it had been decided that three types of airborne equipment would be tested:

1. DME Interrogator, Model DIA

   Peak power output - 1 kw
   Receiver sensitivity - 112 dbw

2. DME Interrogator, Model DIB

   Peak power output - 0.5 kw
   Receiver sensitivity - 105 dbw

3. Variable Parameter DME Interrogator (VPDI)

   Peak power output - - 4 kw
   Receiver sensitivity - 114 dbw

Item 1, manufactured by Federal Telecommunication Laboratories, is shown in Fig. 11. In general it has the characteristics desirable of an interrogator for airline and other commercial use.[4] Item 2, manufactured by the Hazeltine Electronics Corporation, is shown in Fig. 12. In general, it has characteristics desirable of an

[4] J. R. Hoffman, R. E. Carlson, "Recent Improvements to DME Interrogators," CAA TD Report No. 212, June 1953.

interrogator for private and business-type aircraft.[5] Item 3 is an especially redesigned Model 1356 Hazeltine Electronics Corporation interrogator for DME system testing, developed at TDEC.[6]

Flexibility was stressed in the VPDI design. Both the transmitter and receiver may be manually and continously tuned, and each employs a separate antenna. Output power level, receiver sensitivity, and code and decode pulse spacings may be varied in flight. The purpose of VPDI employment in this flight test was to assure that frequency-compatible paths would be obtained on both interrogation and reply and to take advantage of its higher power output and receiver sensitivity. This unit is shown in Fig. 13.

Inasmuch as the VPDI requires separate antennas for transmitting and receiving, it was necessary to provide a total of four antennas on the B-36. Two of these were half-wave vertical stubs installed beneath the nose of the aircraft. Each of the other two antennas consisted of a pair of vertical half-wave stubs, one of which was installed on the right side of the aircraft and the other on the left side. These antennas departed from the vertical by approximately 30 degrees. The two stubs of each pair were connected in parallel through a T junction matched to present a 52-ohm impedance.

The VPDI, being fundamentally only a transmitter and receiver having no ranging and tracking circuits, requires a synchroscope for observing the reply pulses and for determining their distance. The synchroscope is also used as a tuning indicator. A Du Mont Type 256-D synchroscope was selected for this application due to the accuracy of its timing circuitry. The standard Type 256-D synchroscope provides range strobing to only 1000 microseconds. This was modified to provide strobing to 3000 microseconds. Ranges in excess of 3000 microseconds were measured using the 4500 microsecond sweep in conjunction with crystal markers. The synchroscope had been tested previously for satisfactory operation and calibration accuracy when operating from 400 cps power supply. The complete airborne installation is shown in Fig. 14. Two DIB and two DIA interrogators may be seen. One each of these equipments was taken as a spare.

[5] C. C. Trout, W. E. Haworth, "Development of Lightweight DME Interrogator, Model DIB," CAA TD Report No. 228, January 1954.

[6] R. C. Borden, R. E. Carlson, J. R. Hoffman, H. G. McMurtrey, "Development of a Variable Parameter DME Interrogator," CAA TD Report No. 246, September 1954.

Since the DIB interrogator was originally designed for tracking and searching to 100 statute miles only, it was necessary to modify the circuits to provide operation to 300 statute miles. This was accomplished simply by making the appropriate RC circuit changes. The DIA interrogator was also designed for range search, track, and indication to 100 nautical miles. Because an electro-mechanical strobing range unit is employed in the DIA equipment, more extensive modifications were required than in the case of the DIB interrogator.

Following the installation, all interrogators and the VPDI were ground checked. The Rapid City, South Dakota DTB transponder, located about four miles from the Ellsworth Air Force Base provided a means of checking the systems. All units successfully interrogated and received signals from this transponder.

Take-off for the flight test was at 2400, CST, January 11, 1954, on a scheduled 20-hour flight. Routine air force training missions were conducted at 15,000 feet during the first 9 hours of the flight; however, this time afforded TDEC engineers an opportunity to check operation of the installed DME units since the aircraft passed within range of a number of CAA transponders. During this portion of the flight the following DTB transponders were picked up: Lexington, Nebraska; Grand Island, Nebraska; Butler, Kansas; Kansas City, Missouri; Wichita, Kansas; St. Joseph, Missouri; Springfield, Missouri; Memphis, Tennessee; Atlanta, Georgia; Spartanburg, South Carolina; and Charleston, South Carolina.

In general, the maximum distances obtained were from 150 - 170 statute miles. However, ranges up to 212 statute miles were obtained from the Spartanburg station while the aircraft was still at 15,000 feet.

Upon reaching Parris Island, South Carolina, the aircraft proceeded due north and after flying over Shaw Air Force Base, South Carolina, began the ascent from 15,000 to 40,000 feet. An altitude of 40,000 feet MSL was reached at 0930 CST, at which time the aircraft was on a heading 310° true to Indianapolis. At 1007 CST transmissions from the MOPAT were first observed at the VPDI receiver output. At 1030 CST, the VPDI successfully interrogated the TDEC ground station and the reply was observed synchronized at 246.5 statute miles. The aircraft passed over at 1153 CST. Computing ground speed between 1030 and 1153 CST and extrapolating back to 1007 CST indicated that at the time transmissions were first observed, the aircraft was 314.9 statute miles from the station.

During the inbound flight, the DIA latched on at 212 statute miles and the DIB at 234 statute miles. Atlanta ILS DME was indicated at 253 statute miles on the DIA. After flying over Indianapolis, the aircraft assumed a course of 057° and on the outbound leg, synchronized reply signals were obtained to 248 statute miles with the VPDI.

In this case, the reply path failed before the interrogation path. It was not possible to determine how much longer the interrogation path would have lasted. The reversal of path failures inbound and outbound is believed due to the fact that the receiving antenna was located in the nose of the aircraft and the transmitting antennas were on the side of the fuselage.

## CONCLUSIONS

It is concluded that the addition of the rf amplifier and the MOPAT transmitter to a standard DME ground station provides a means of approximately doubling the free-space range. In actual practice this advantage is seldom realized due to the fact that present day aircraft seldom fly high enough to maintain line-of-sight to the ground station at the maximum distances which may be obtained.

Implementation of the new equipment would provide an additional tolerance on both interrogator and reply paths, which in many cases might be helpful in over-riding the signal reduction introduced by null areas, either in the airborne antenna polar patterns or caused by frequency instability, or by other variables previously discussed. However, the present DME system is refined to the degree that solid coverage is generally obtained within the line-of-sight limitation, with the exception of combinations of unfavorable factors, such as aircraft banking in a ground null area. An additional 6 db still could not prevent loss of signal in all cases; and as long as the unmodified DME remains operationally acceptable, it is doubted that mass conversion of standard transponders is economically feasible. A multitude of problems associated with monitoring, maintenance, outages, procurement, etc., would certainly accompany such a nationwide conversion.

On the other hand, when ground station siting is such that coverage at the lower altitudes (20,000 feet and below) can be increased appreciably by addition of MOPAT and the rf amplifier, it may be feasible to make modifications.

One advantage of a higher powered and more sensitive transponder is the resultant simplification of the airborne equipment which may be accomplished. It has been found that an output of 500 watts is the lowest which will still provide reliable service with present ground receiver sensitivities. An effective increase of 6 db in ground receiver sensitivity would permit a reduction in airborne interrogator transmitter output to 125 watts. Inasmuch as the present trend in interrogators is toward direct crystal control, in spite of the difficulty of obtaining power amplification at the output frequencies, a step in the direction of lower power would significantly reduce the size and complexity of the transmitter.

Increased transmitter output from the transponder would in like manner permit a simpler interrogator receiver.

It should be pointed out, however, that unless all transponders are modified, interrogator manufacturers cannot relax the power and sensitivity requirements of airborne units.

## APPENDIX I

### Calculation of Free-Space Range of DME Systems

DME is a two-way communication system, and is valueless unless satisfactory reception is obtained on both interrogation and reply paths. In order to compute the free-space range of the system, it is necessary to calculate separately the maximum range for both the interrogation and reply paths and then to accept the lesser of these two as the system free-space range.

Fundamentally, the free-space range of a communication link at a given wave-length is determined by the radiated power and by the minimum detectable signal level of the receiver. When either the receiving or transmitting antenna or both have gain, this factor must also be considered. In a practical system, losses incurred in rf transmission cables cannot be ignored, particularly at the shorter wavelengths.

The calculated free-space range of a system provides a figure which may be conveniently used in comparing the range capability of two like systems which differ in sensitivity and power characteristics; but, it should not be considered as a practical maximum range capability figure of either system. The most significant single reason why this cannot be done is the wide variation during actual operation of the instantaneous effective antenna gains. As explained in this report, the effective antenna gains vary with aircraft distance, altitude, and attitude.

The maximum usable range of a one-way communication path may be computed from the general transmission formula

$$P_r = P_t \frac{A_t \; A_r}{\lambda^2 \; d^2} \tag{1}$$

or

$$d = \left( \frac{P_t \; A_t \; A_r}{\lambda^2 \; P_r} \right)^{1/2} \tag{1a}$$

where: $d$ = free-space range, in the same units as $\lambda$

$P_r$ = minimum detectable signal level in watts at the receiver terminal

$A_t$ = effective area of transmitting antenna = $\frac{G_t \lambda^2}{4\pi}$

$A_r$ = effective area of receiving antenna = $\frac{G_r \lambda^2}{4\pi}$

$P_t$ = power output of transmitter in watts

$\lambda$ = operating wavelength, in any convenient units

$G_t$ = transmitting antenna gain, as a dimensionless power ratio

$G_r$ = receiving antenna gain, as a dimensionless power ratio

From the above formula and the data in Table I, the free-space range of various equipment combinations may be calculated. These values are enumerated in Table II. In each case the underlined value denotes the limiting range for the system under consideration.

TABLE I

| Equipment | $P_t$ (kw) | $G_r$ | $G_t$ | $P_r$ (dbw) |
|---|---|---|---|---|
| DTB | 5 | 4 | 4 | -118 |
| DTB (with Pre-Amp) | 5 | 4 | 4 | -124 |
| DTB (with MOPAT) | 20 | 4 | 4 | -118 |
| DTB (with both Pre-Amp and MOPAT) | 20 | 4 | 4 | -124 |
| DIA | 1 | 2 | 2 | -112 |
| DIB | 0.5 | 2 | 2 | -108 |
| VPDI | 4 | 2 | 2 | -114 |

Note: (1) For interrogation path calculations $\lambda$ = 30.8 cm.
For reply path calculations $\lambda$ = 25 cm

(2) 6 db cable loss is included in each calculation (3 db ground plus 3 db airborne)

TABLE II

FREE SPACE RANGE OF DME EQUIPMENTS
(Statute Miles)

| DME Type | /DIA/ | | /DIB/ | | /VPDI/ | |
|---|---|---|---|---|---|---|
| Transponder | Interrogation | Reply | Interrogation | Reply | Interrogation | Reply |
| DTB | 538 | 453 | 380 | 276 | 1076 | 567 |
| DTB and Pre-Amp | 1076 | 453 | 760 | 276 | 2152 | 567 |
| DTB and MOPAT | 538 | 906 | 380 | 552 | 1076 | 1134 |
| DTB, MOPAT and Pre-Amp | 1076 | 906 | 760 | 552 | 2152 | 1134 |

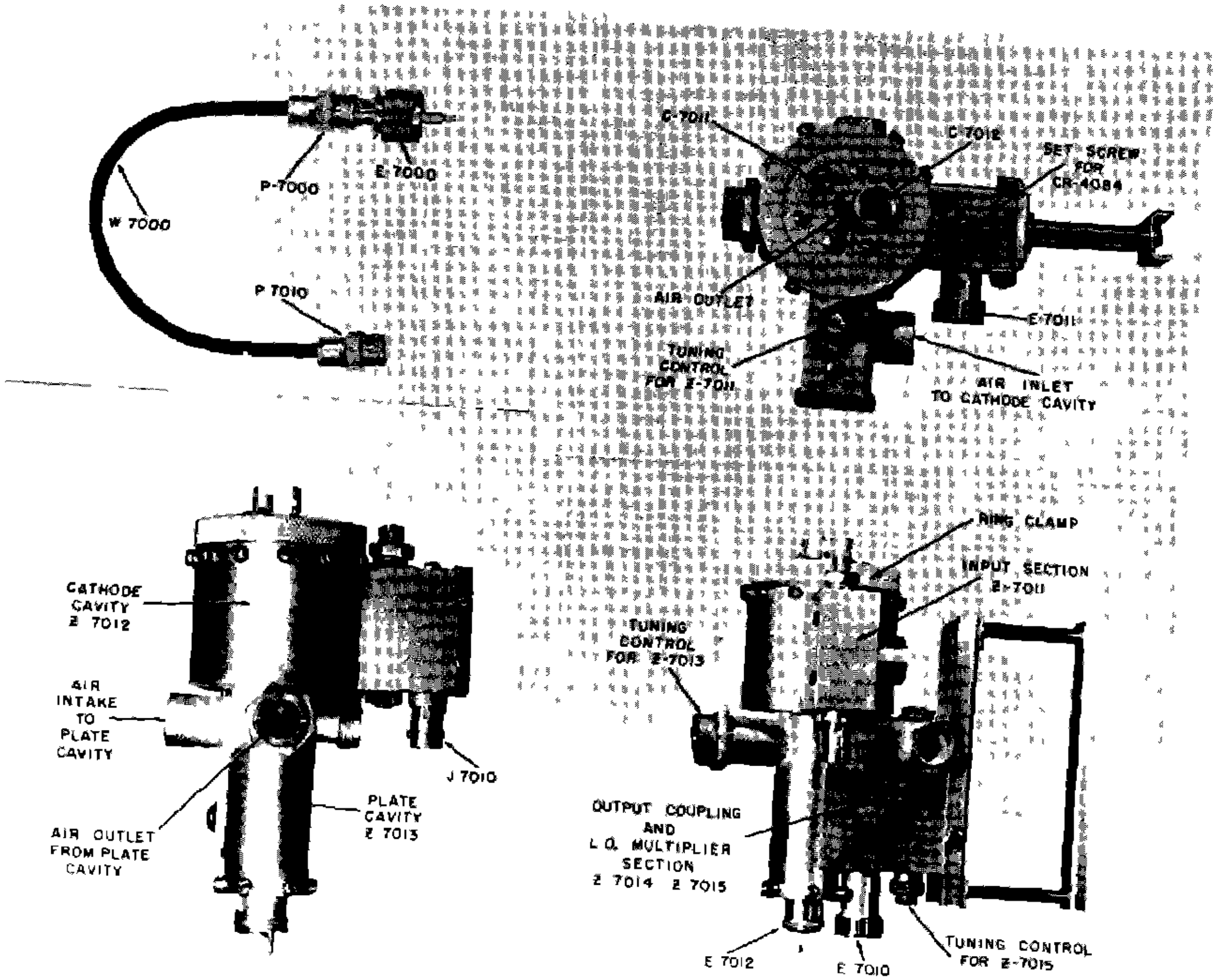


FIG 1 RF AMPLIFIER

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

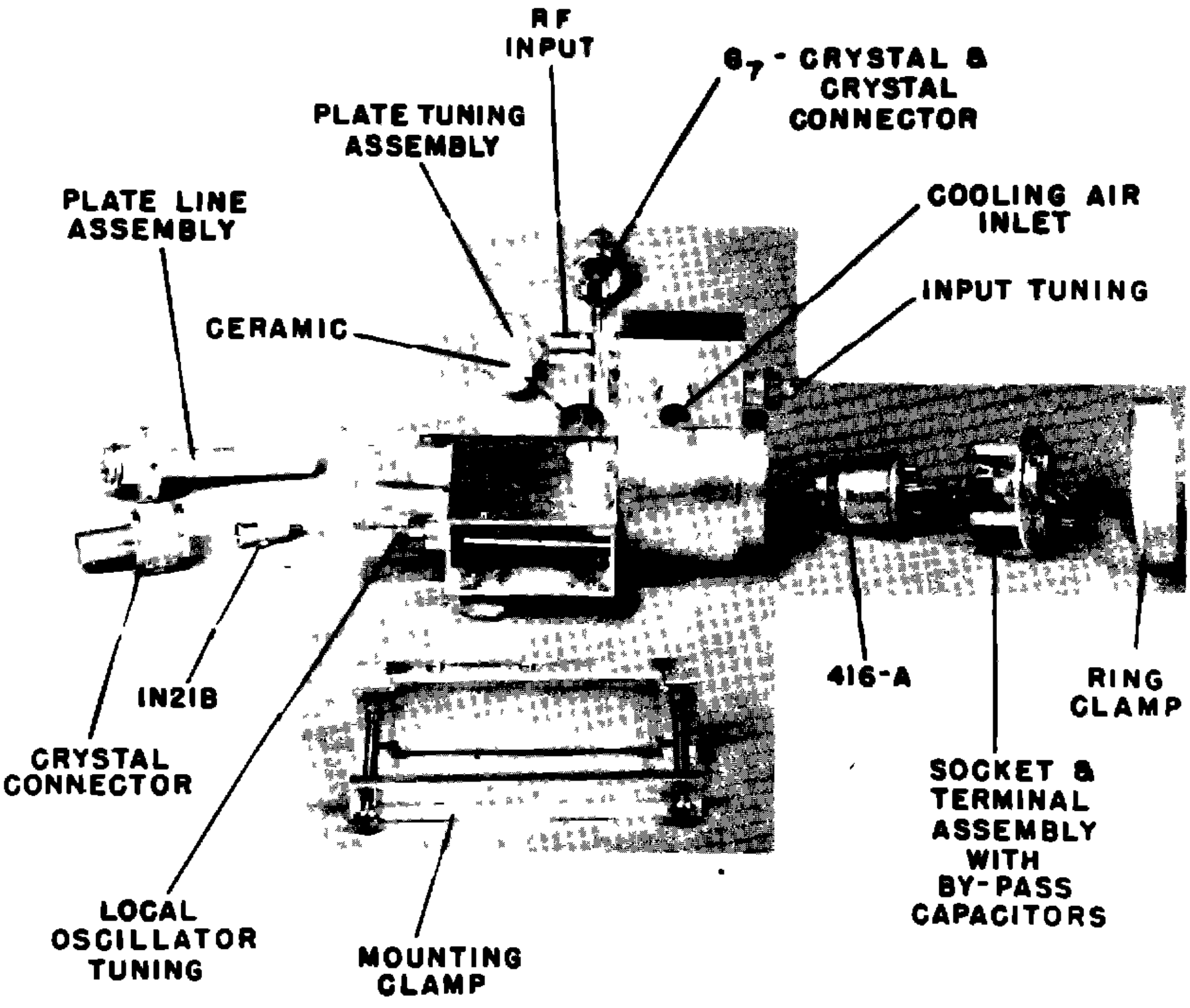


FIG.2 RF AMPLIFIER, DISASSEMBLED

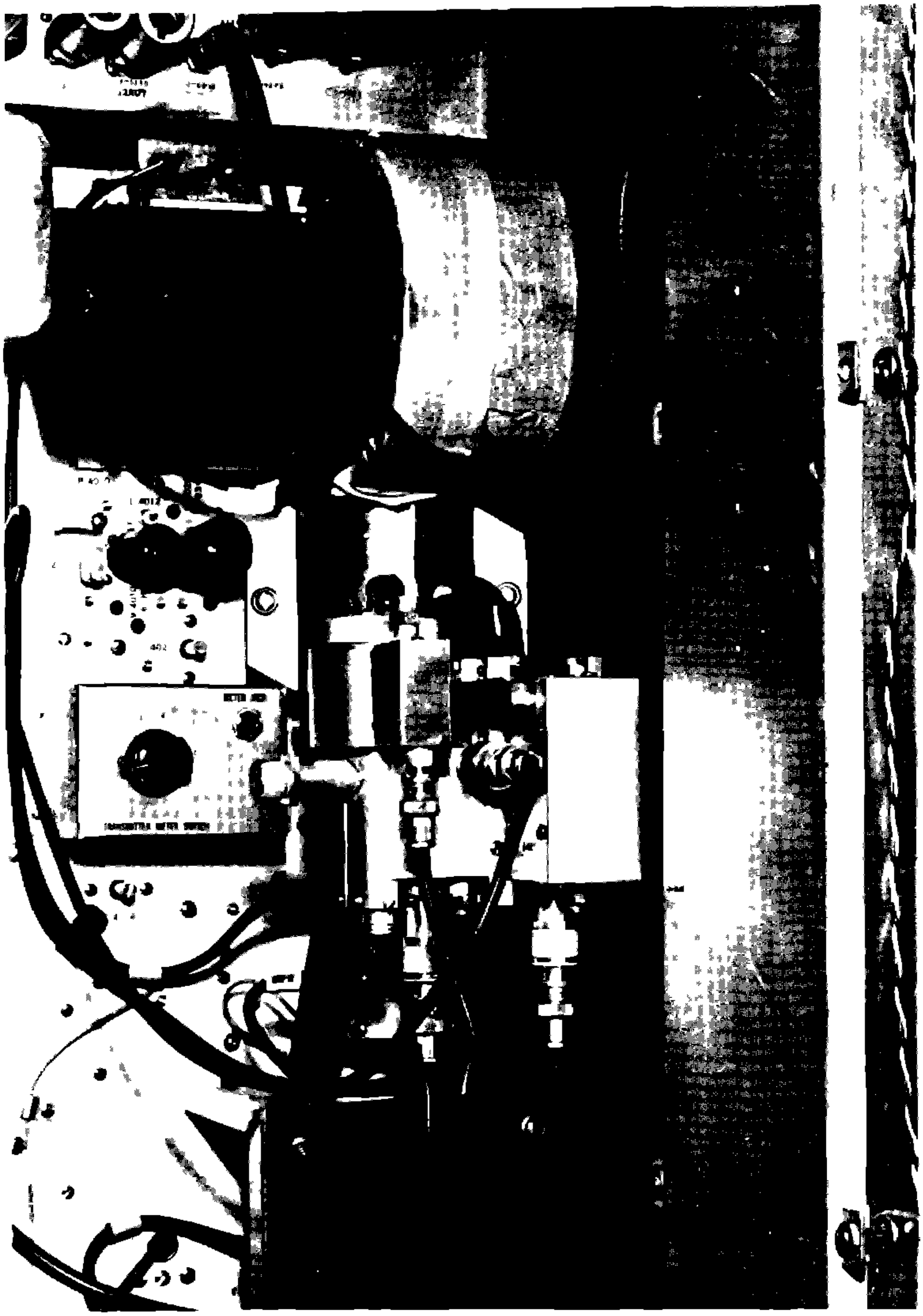

FIG. 3 RF AMPLIFIER, INSTALLED IN DTB TRANSPONDER

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

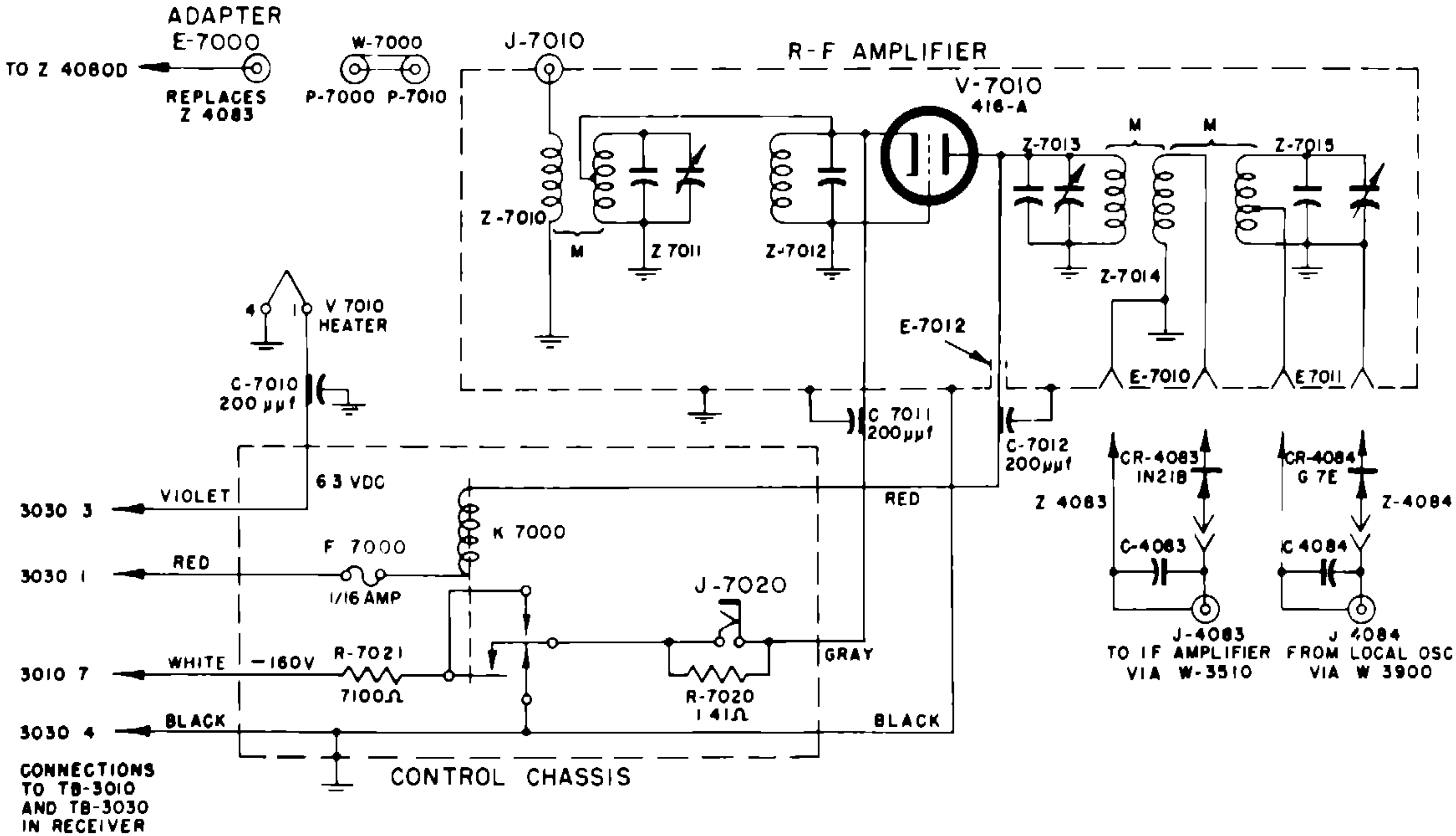


FIG 4 SCHEMATIC DIAGRAM, RF AMPLIFIER

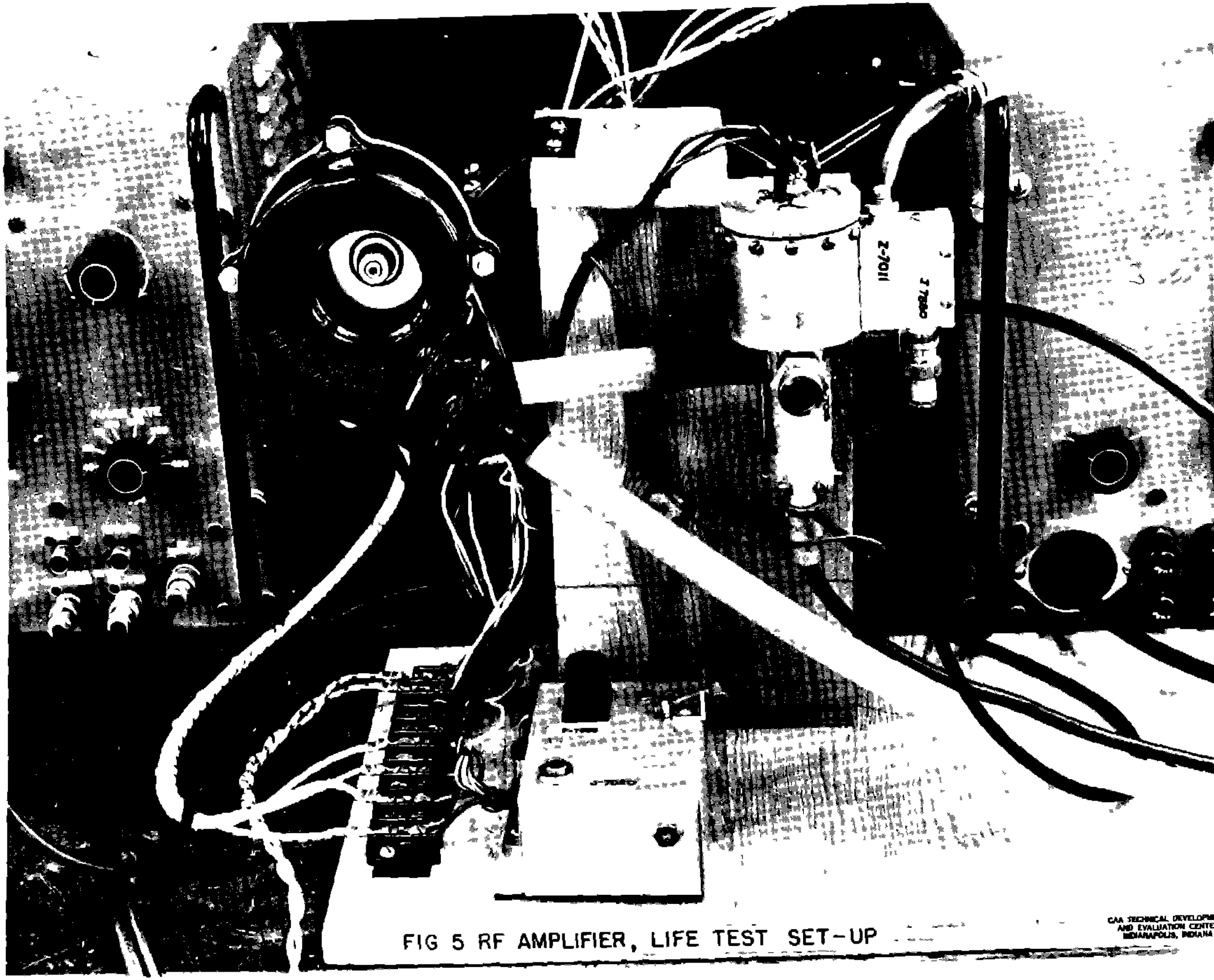

FIG 5 RF AMPLIFIER, LIFE TEST SET-UP

CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS, INDIANA

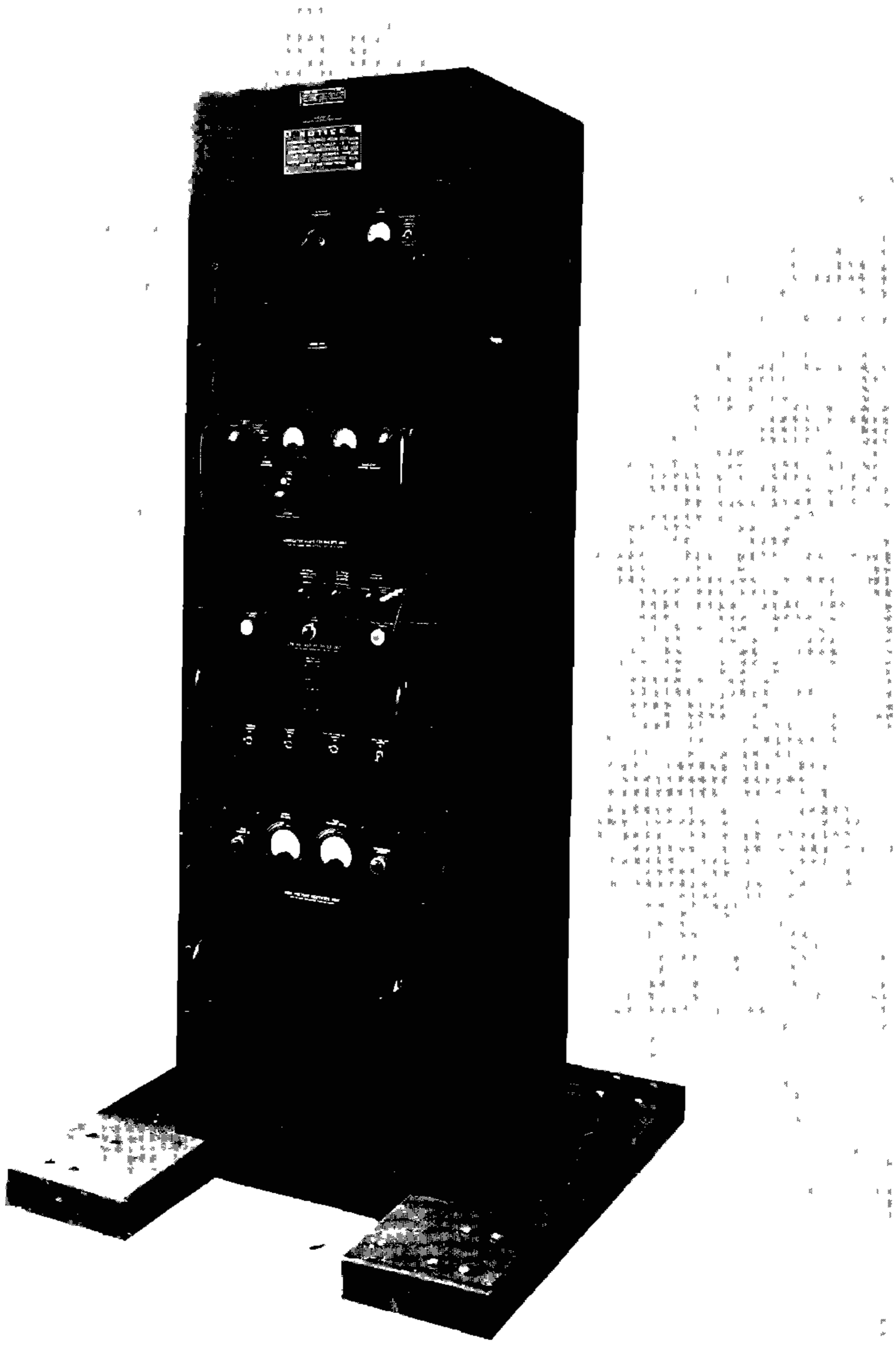

FIG 6 MOPAT (MASTER OSCILLATOR POWER AMPLIFIER)

CAA TECHNICAL DEVELOPMENT
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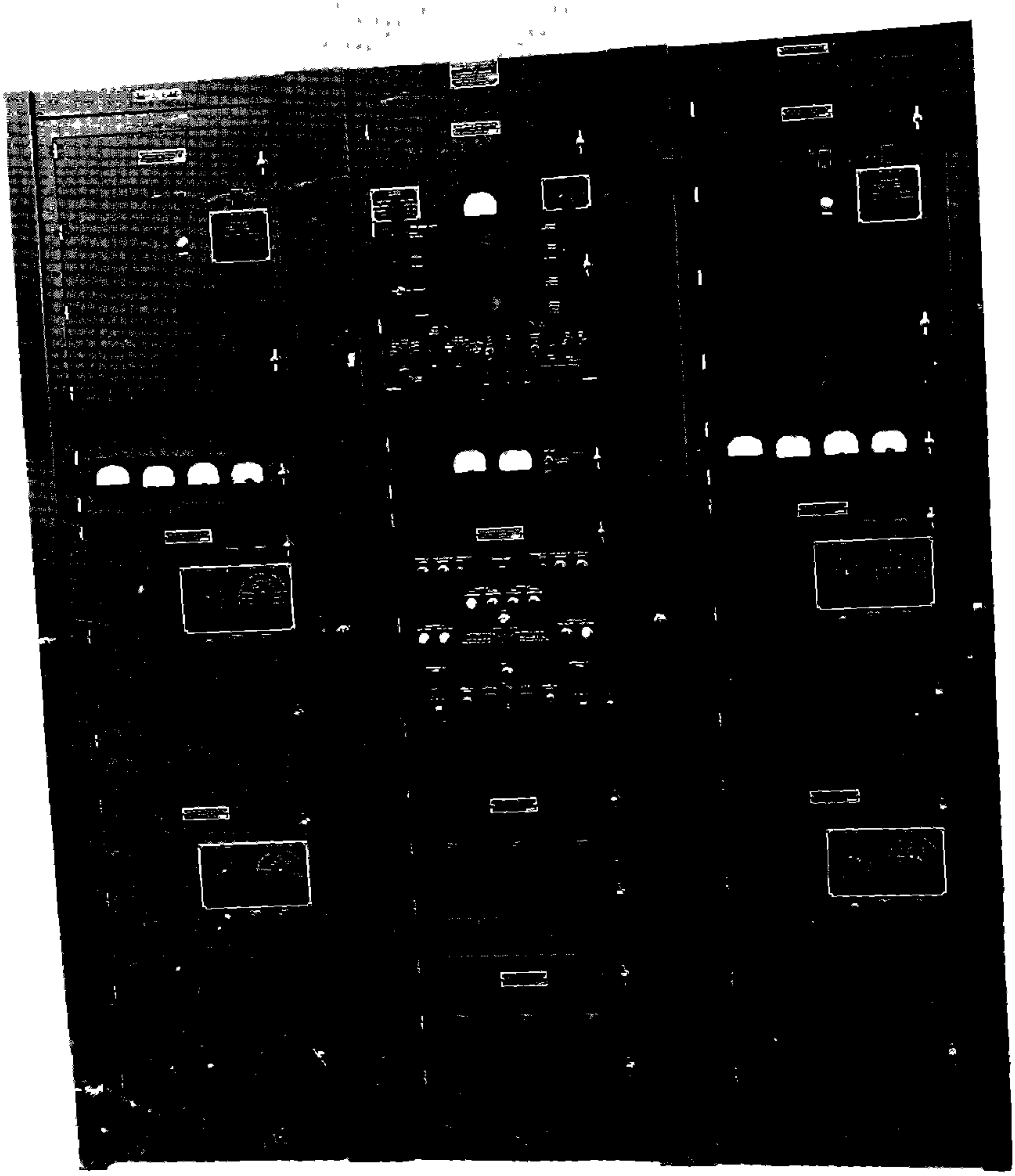

FIG 7 MODEL DTB TRANSPONDER

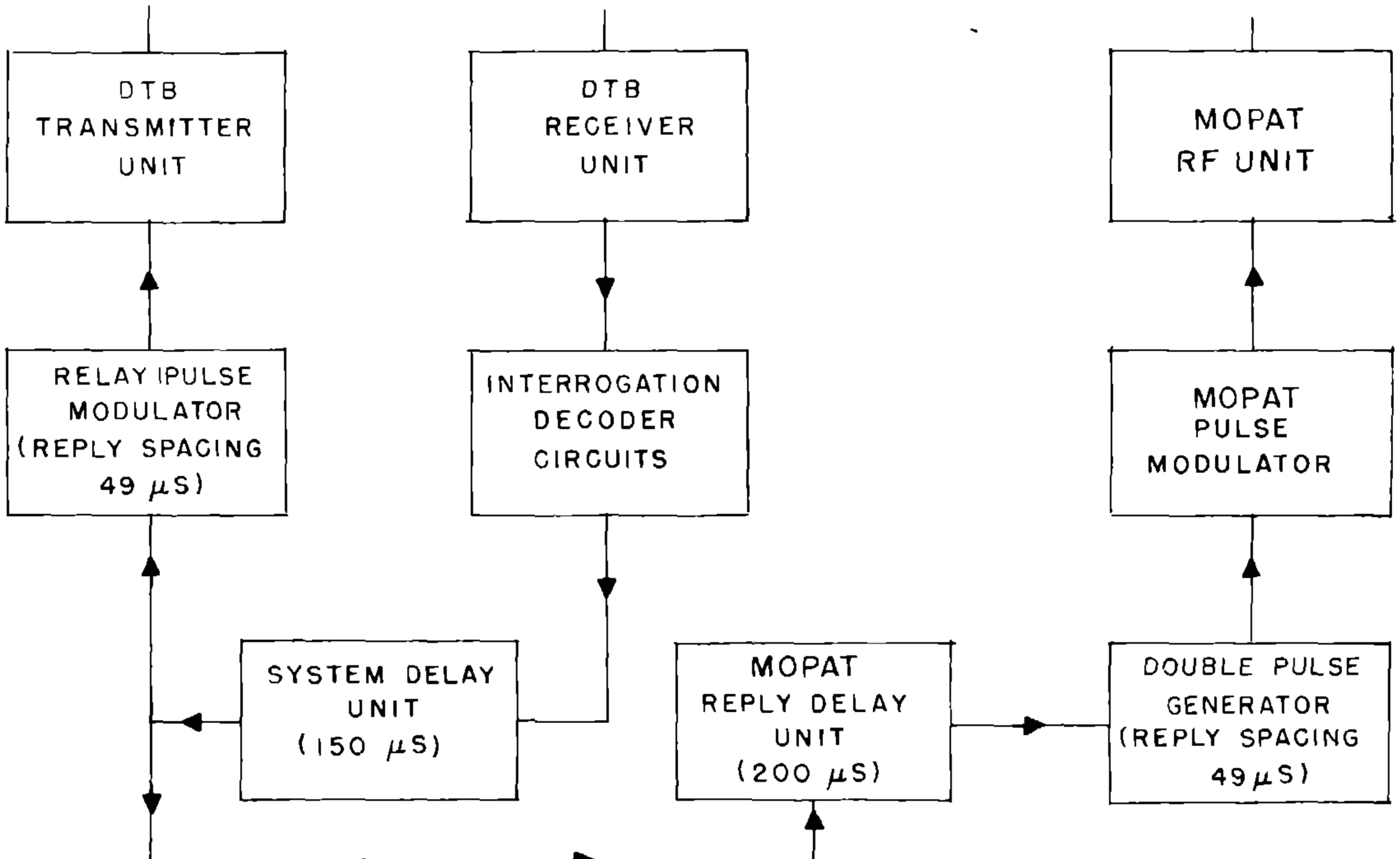


FIG 8, BLOCK DIAGRAM OF GROUND—EQUIPMENT CONFIGURATION

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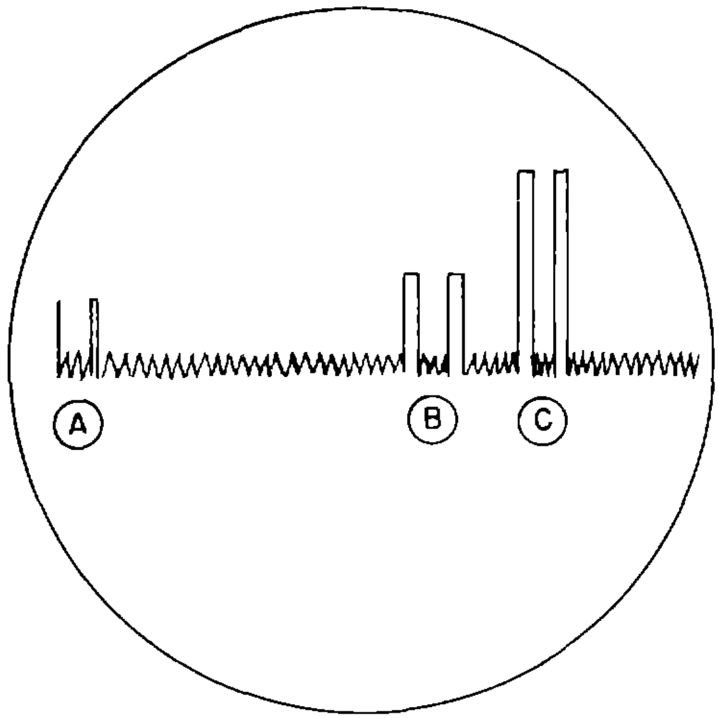


(A) FEED-THROUGH OF INTERROGATION PULSES

(B) DTB REPLY PULSES

(C) DTB MOPAT PULSES

FIG 9, INTERROGATOR-RECEIVER OUTPUT PATTERN

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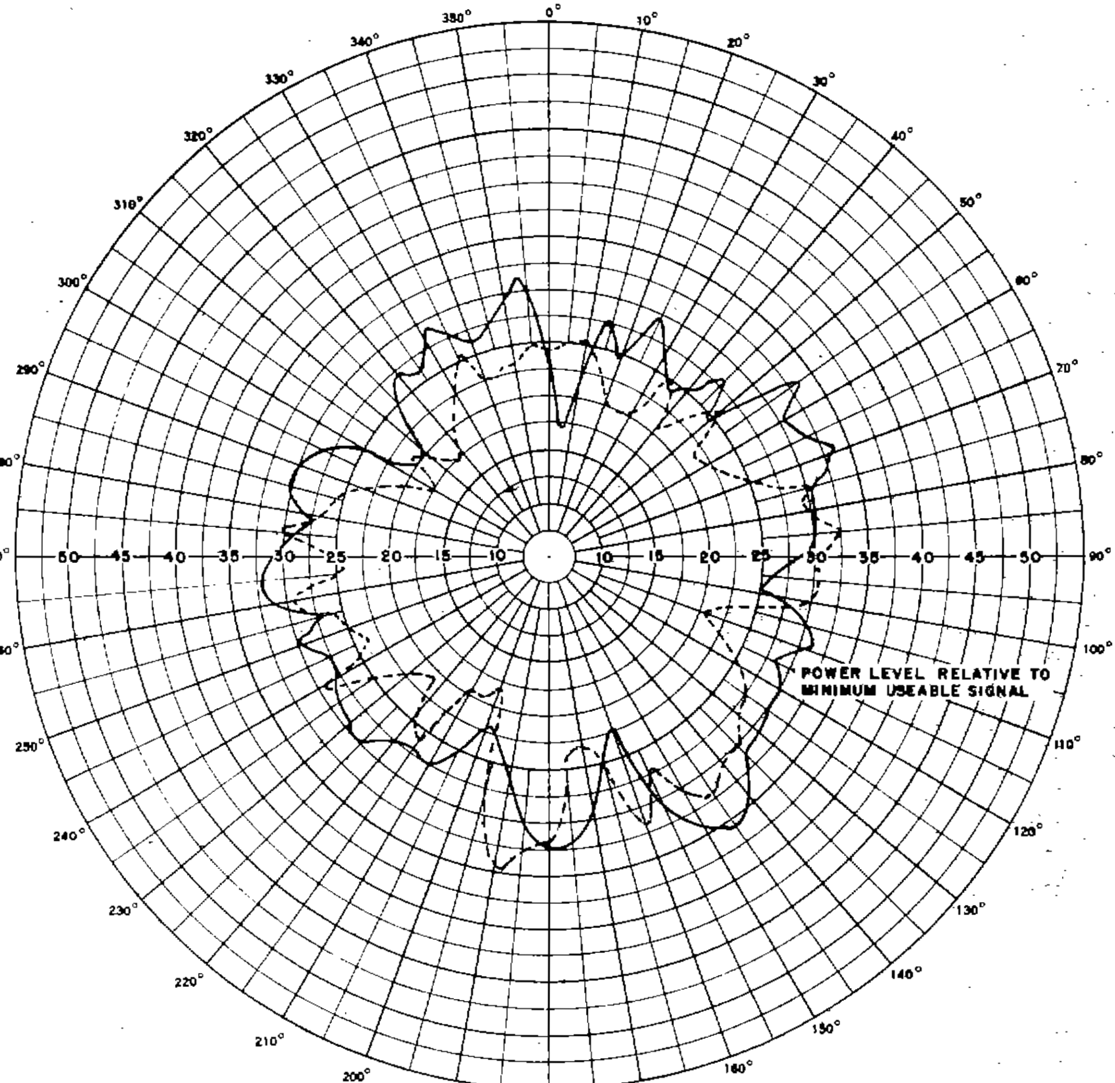


20 MILE RADIUS
ALTITUDE 1000 FT. ABOVE TERRAIN.
——— MOPAT
- - - - - - DTB

FIG. 10 MOPAT AND DTB FIELD-STRENGTH PATTERNS

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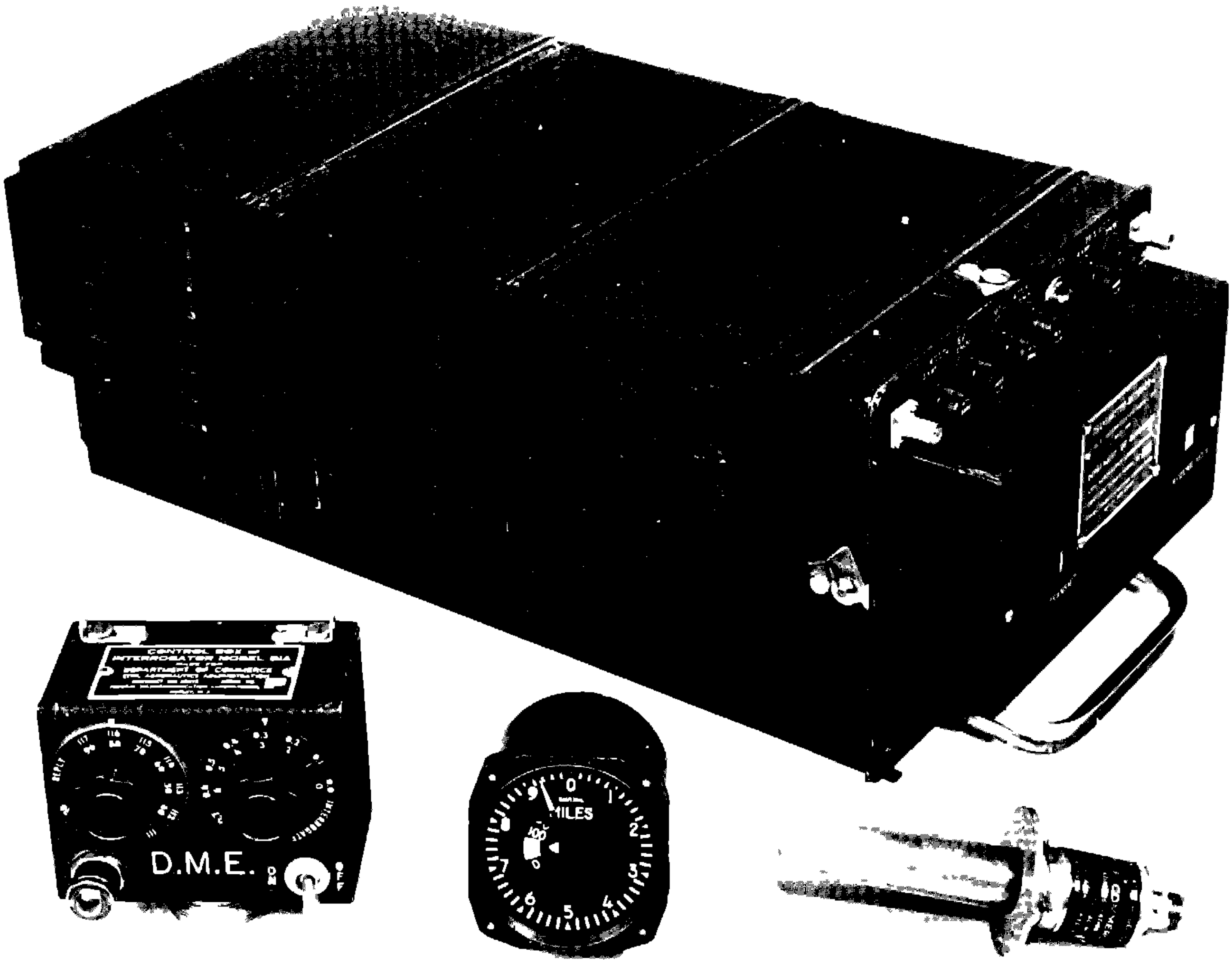


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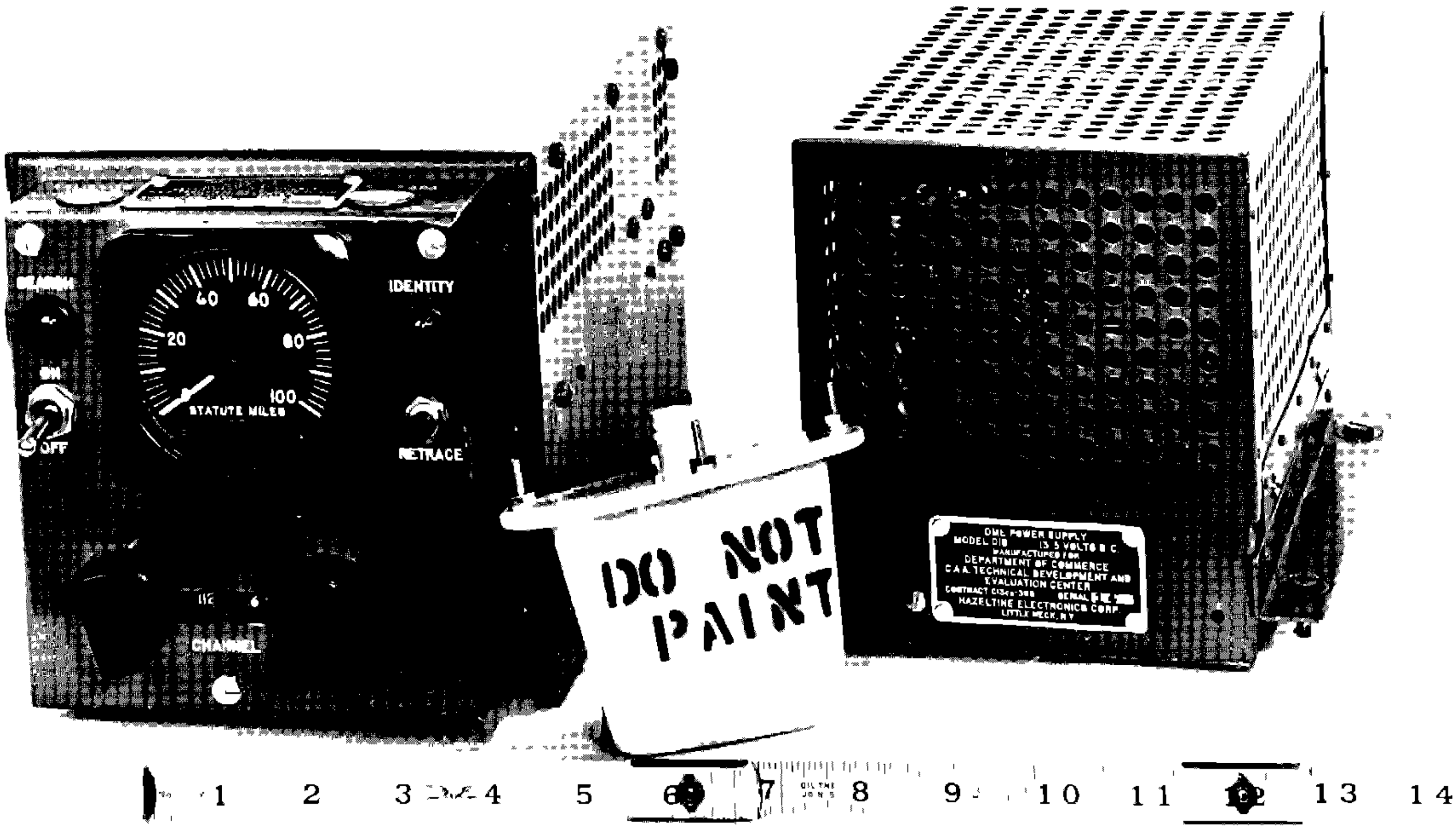


FIG 12 DIB INTERROGATOR

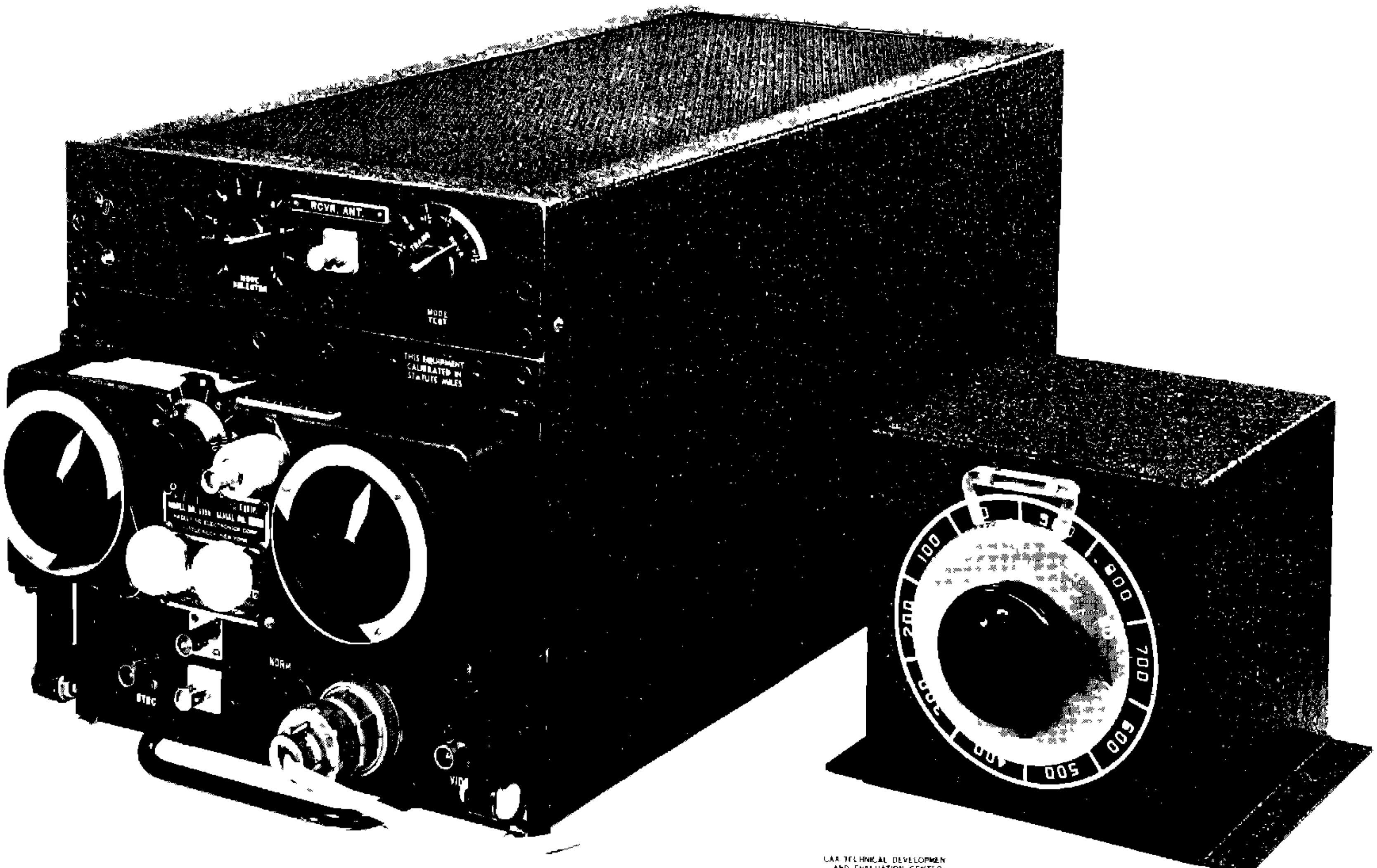


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FIG 13 VARIABLE PARAMETER DME INTERROGATOR

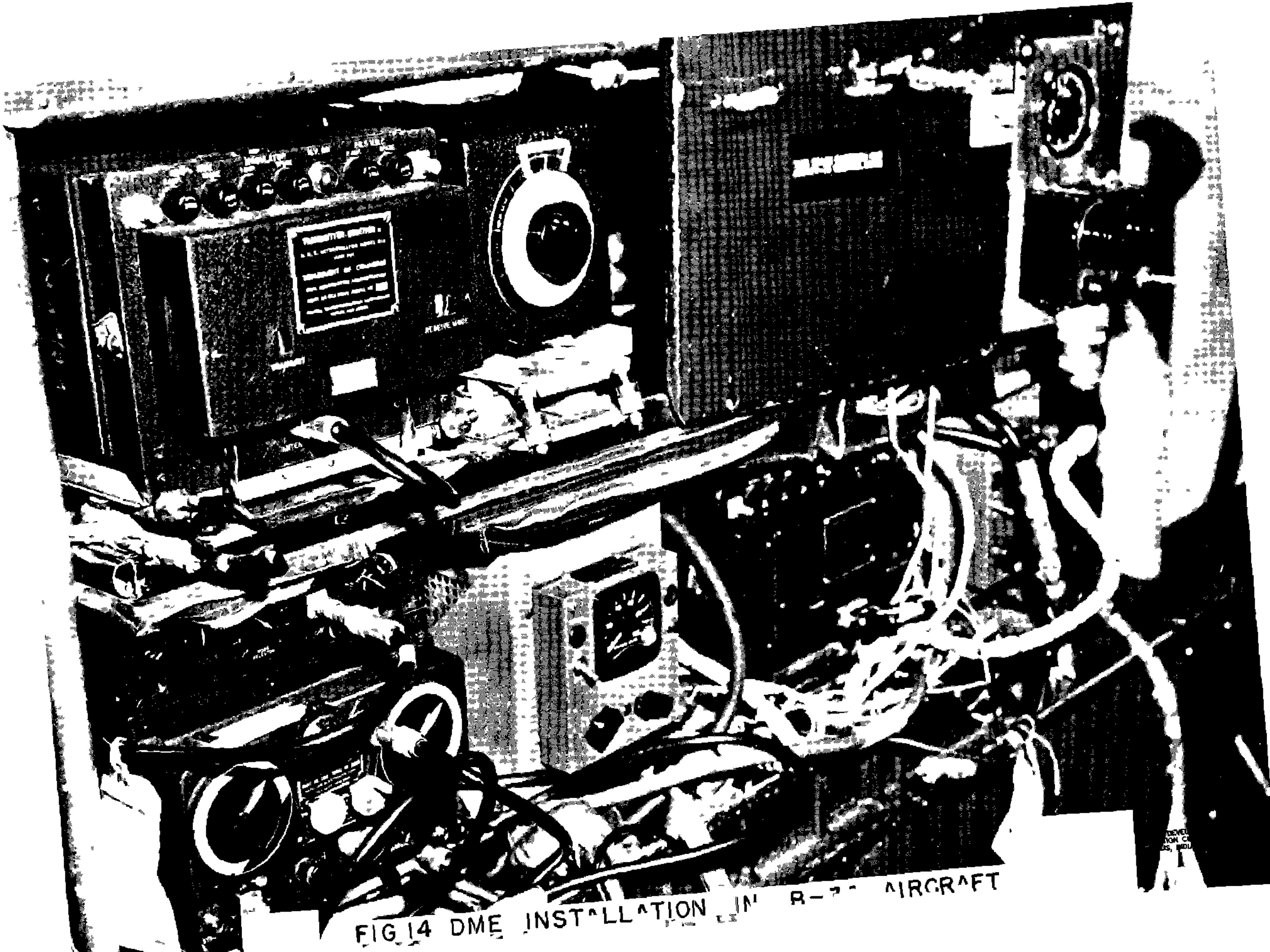

FIG 14 DME INSTALLATION IN B-?? AIRCRAFT